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The Royal Observatory of Belgium (ROB) is heavily involved in the EUREF Permanent Network (EPN) and is processing GNSS observations from the EPN since February 1996. Nowadays, the errors due to the reference frame definition and the Earth's atmosphere (ionosphere and troposphere) still remain the main limiting factors when performing high accuracy GNSS positioning. In that framework, the ROB carries a long-term research program that aims to better understand these error sources, to improve their mitigation in GNSS data processing and to provide specific products for the scientific community.

1. Ongoing Research

1.1 Reference Frame Definition

We extended the investigation of the influence of the network effect within regional GNSS networks (Legrand et al., 2010; Legrand et al., in press). In 2010, the ITRF2008 and new homogeneously reprocessed regional (and global) solutions were tested. The agreement (RMS of position/velocity differences) of these new solutions with the ITRF2008 improved with a factor three compared to the previous study (using ITRF2005). Consequently, also the error caused by the network effect was reduced. It can nevertheless still reach 1 mm/yr in the vertical and 0.5 mm/yr in the horizontal. Despite the improvement seen on the estimated positions and velocities when using the reprocessed ITRF2008, it was also shown that the use of the new improved reference solution did not impact the residual position time series which are still significantly affected by the network effect: in a regional network analysis the amplitude of the annual and semi-annual signals are underestimated in all components of the station time series (27% resp. 15% reduction of the annual resp. semi-annual signal in the height component). In addition, also the phase of the annual and semi-annual signals is altered.

1.2 IAG Working Group 'Regional Dense Velocity Fields'

ROB heavily contributed to the activities of the IAG Working Group on "Regional Dense Velocity Fields" (see http://epncb.oma.be/IAG). With the goal to generate a high-quality position/velocity solution for a core network of GNSS stations (in addition to the ITRF2008), several newly reprocessed global and regional cumulative position and velocity solutions (containing about 400 densification sites of the ITRF2008) were submitted to ROB in the summer of 2010. The analysis of these solutions showed that the 3D-RMS of their agreement with the ITRF2008 (after outlier rejection) varies between 0.6 and 1.1 mm/yr; it is extremely good for

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some solutions, while others still require more iterations to reach the required level of agreement. A part of the disagreements often originate in the use of different data time spans within the ITRF2008 and the submitted solution. Some cases were also identified where the residual position time series from the ITRF2008 significantly underperformed compared to the time series from a regional solution. This raised the need for more interaction between the regional reference frame sub-commissions and the IGS and/or the ITRF product center in order to prevent from facing a similar situation in the next release of the ITRF.

1.3 Precise Point Positioning

The software ATOMIUM, developed by ROB and dedicated to Precise Point Positioning (PPP), has been upgraded (Baire et al, in press) to providing the possibility for kinematic positioning. The analysis is performed on daily data batches and provides one position each 5 minutes. This function was already validated with data from the March 11, 2011 Earthquake in Japan.

1.4 Antenna Calibration Models

We are performing a study aiming at determining the impact of the new IGS08.atx GNSS receiver antenna calibrations on the estimated GNSS station coordinates. Preliminary results show that coordinate differences, obtained by using on one hand the old IGS05 calibration model and on the other hand the IGS08 model, can reach up to 4 mm in the horizontal and 8 mm in the vertical. More results are given in Baire et al. (this volume).

2. Services and products based on the EPN

2.1 E-GVAP Analysis Centre

The ROB has continued to develop and maintain an analysis centre in order to participate to the EUMETNET EIG GPS Water Vapour Program (E-GVAP II, Pottiaux, 2009a). In that context, ROB provides the meteorological institutes with near real-time Zenith Path Delay (ZPD) estimates from a regional network of EPN stations (Fig. 1) for data assimilation in operational Numerical Weather Prediction models. Stations from national densification networks are added to improve the ROB contribution to E-GVAP. In 2010, the total number of stations processed by ROB was about 210. Several of GNSS stations in this network are located nearby other instruments such as radiosondes, water vapour radiometers... Thanks to the memorandum of understanding signed by EUREF and EUMETNET, this co-location allows ROB to validate its analysis strategy and to assess the accuracy of its ZPD estimates by cross-technique comparisons (Pottiaux et al., 2009b). It was demonstrated that all requirements for GNSS-meteorology are achieved by the ROB E-GVAP analysis centre (Pottiaux, 2009a), in particular the cross-comparison with the EPN troposphere combined products showed that 93% of our ZPD estimates have a precision better than 5.5 mm.

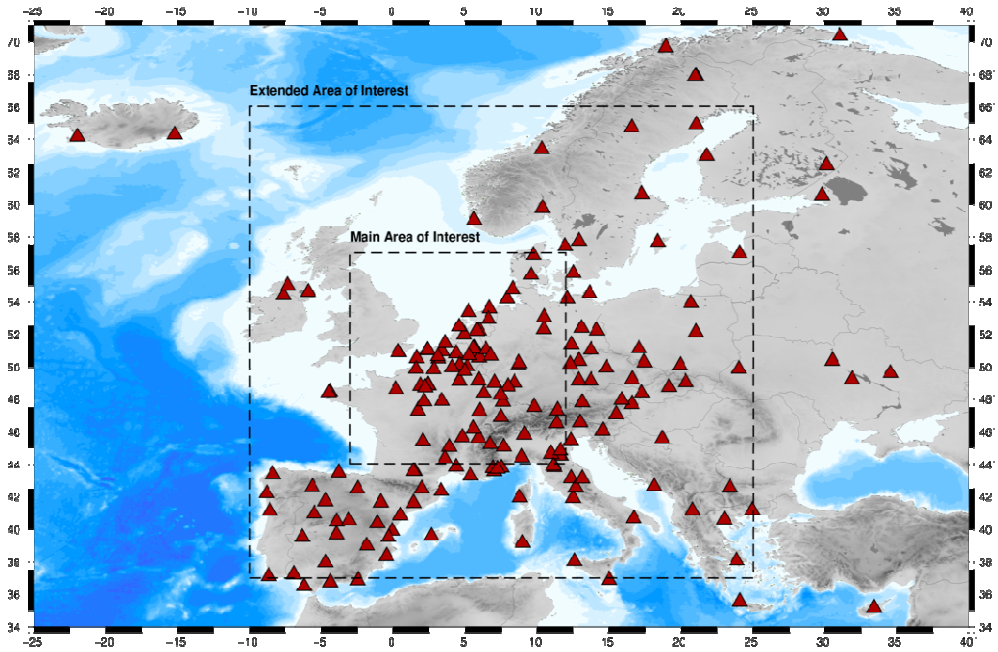

Figure 1: GNSS network processed in near real-time in the framework of E-GVAP. A few stations, notably in Greenland and in the Atlantic regions, are located outside the map area

2.2 European VTEC maps

ROB continued its investigation of the optimal method to deliver VTEC maps in near-real time over Europe from the EPN data. Different parameters, input data, and interpolation methods have been tested in order to produce in near-real time, 0.5°x0.5° grid of VTEC maps and maps of the VTEC variance over Europe each 15 minutes (see Figure 2). The results showed that the most adapted interpolation for such a product is the spline interpolation. These VTEC maps were compared with Global Ionospheric Maps (GIMs) and showed good agreement with a mean differences lower than 1 TECU (1TECU=$10^{16}e^{-}.m^{-2}$, except during stormy days when the GIMs seem to underperform. Consequently, the VTEC maps and its variance estimated each 15 minutes over Europe will be a useful product for applications using radio signal especially to notify users of abnormal events (e.g. ionospheric storm). More details are given in Bergeot et al. (this volume).

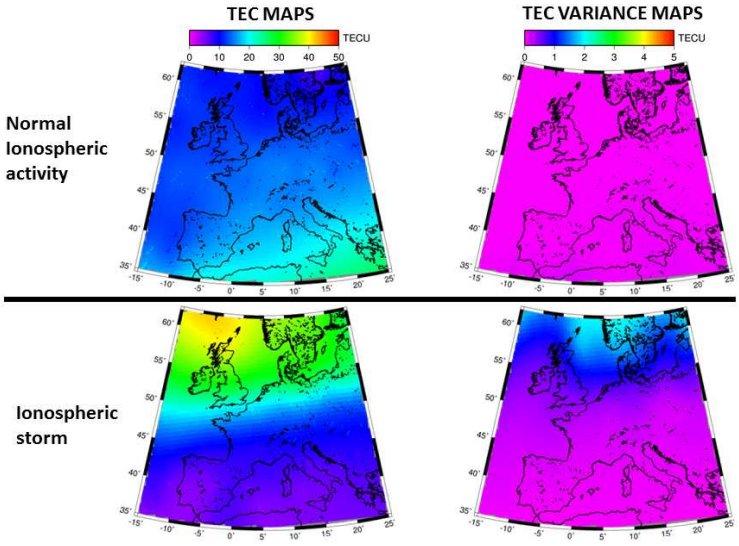

Figure 2: TEC maps over Europe (left) and its variance (right) in TECU estimated over 15 minutes in a near-real time approach, for normal ionospheric activity (top , DOY 303 2003, 12:30-12:45 UT) and during an ionospheric storm (bottom, DOY 303 2003 , 22:30-22:45).

3. Contribution to the EPN

The ROB contributes to the EPN with:

- 4 permanent tracking stations: BRUS, DENT, DOUR and WARE. Recently, two new multi-GNSS receivers (PolaRx3 Septentrio) were installed in Brussels. They were configured to track GPS, Glonass and GIOVE-A and B satellites of the European Galileo system. More multi-constellation receivers will be added in the coming year(s), eventually resulting in capturing multi constellation data in all ROB GNSS stations.
- An EPN Local Data Center (ftp://gnss.be), providing access to the GPS stations operated by ROB.
- An historical EPN data center, providing access to all historical EPN data especially targeting reprocessing activities.
- An EPN Local Analysis Center processing an EPN subnetwork located around the Benelux (see http://epncb.oma.be/_dataproducts/analysiscentres/subnetwork.php?lac=ROB). As its contribution to the EPN reprocessing Pilot Project, ROB contributed to the EPN reprocessing benchmark campaign and submitted a reprocessed solution (1996-2006) for the its subnetwork based in IGS REPRO1 orbits.
- An EPN NTRIP caster to relay the EPN streams from the main EPN NTRIP caster at Bundesamt für Kartographie und Geodäsie (BKG), Germany. This way, ROB guarantees load sharing with the main EPN broadcaster and overall communication traffic reduction. At startup, all streams were relayed from the the main EPN NTRIP caster at BKG. As this created however a single point of failure, now gradually a shift is made to use the several national casters over Europe as sources for the NTRIP stream relay. The EPN NTRIP relay

caster at ROB further evolved from a regional into a redundant top caster. At present about 140 EUREF streams are relayed, from 14 different casters. Users can apply for an account by filling in the web form on http://www.gnss.be/data.php#NTRIPaccess.

- In addition, the ROB hosts the EPN Central Bureau (http://www.epncb.oma.be/). Recently, new software, Qualcheck, to check the quality of the GNSS data of the EPN has been developed. Due to the modernization of GNSS signals, the old software could not anymore meet the EPN Central Bureau needs for monitoring the quality of the EPN stations. This software is already used for the snapshots of satellite tracking at the EPN Central Bureau website. Moreover, the design of this software has been studied to facilitate future developments, including quality checking future Galileo data. For details we refer the interested reader to Bruyninx et al. (in this volume).

4. RTK networks

During the past year the remaining 'old hardware' (GPS only) has been replaced with GNSS receivers and antennas. This means that all the reference stations of the three Belgian RTK networks (Flepos, GPSBru and Walcors) have been upgraded; RTK data containing GPS and Glonass is available for all users nationwide.

5. Levelling network

The entire levelling network, consisting of 19000 benchmarks has been re-observed during the last two decades of the 20th century. Since the end of the year 2000 the NGI didn't perform any systematic precise spirit levelling and we had no plans to restart either.
But several surveyors reported that, in the region of the port of Antwerp, they obtained a systematic difference between heights derived from RTK observations and the levelling results starting from our benchmarks. Some other facts, independent from height observations, confirmed our suspicion that the area subsided.
We determined the borders of the subsiding zone and performed the levelling observations for all the benchmarks in the zone and a buffer zone around it, in order to be able to tie the observations to stable benchmarks.
The final computations showed that in the hart of the subsiding area benchmarks had gone down by 13 cm.

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